Interpolation of METRIC Evapotranspiration Maps for Future Eastern Snake Plain Aquifer Model Versions Using Normalized Difference Vegetative Indices

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INTRODUCTION

Evapotranspiration associated with irrigated cropland is an essential component of the water budget in modeling the Easter Snake Plain Aquifer. Rounding acreage to 2,000,000 irrigated acres and assuming that net evapotransipration (ET) depth is 2.5 feet, the annual volume of ET is approximately 5,000,000 acre feet. This is equivalent to an annual average of 6,900 cubic feet per second, which exceeds the combined discharge of springs in the Thousand Springs area.

In Eastern Snake Plain Aquifer Model versions 1.1 and 2.0 (ESPAM1.1 and ESPAM2.0 respectively), crop evapotranspiration has been represented using county-wide crop mix from National Agricultural Statistics Service and other data, crop coefficients from ET_{Idaho} (Allen and Robison, 2006; 2009) data, and reference evapotranspiration from ET_{Idaho} data. Adjustments for chronic departures from standard conditions were made using ET adjustment factors (Taylor and Contor, 2010). These were calculated using ET data (IDWR, 2011) for a limited number of years processed using METRIC methodology (Allen et al, 2007; Garcia et al, 2009). In ESPAM1.1 these were global adjustments, both spatially and temporally; that is, a single pair of ET adjustment factors (sprinkler and gravity) served for all irrigated parcels and all stress periods. In ESPAM2.0 these varied spatially but not in time.

In ESPAM1.1, ad-hoc manual adjustments were made for acute year-to-year departures from non-standard conditions due to acute water supply constraints (Contor, 2004(a), 2004(b)). In ESPAM2.0 this adjustment was formalized in the On-Farm algorithm of the MKMOD recharge-calculation software (Wylie, 2011; IDWR, 2011(b)).

These methods were employed because of the limited temporal availability of METRIC images. However, it is anticipated that for future versions of ESPAM, METRIC processed estimates will be available for more years in the calibration period. In a year when a METRIC image is available, it is superior to the ESPAM1.1/ESPAM2.0 methods in the following ways:

1. The spatial resolution is 30 to 60 meters (depending on underlying satellite data) rather than county-wide.

2. METRIC estimates are not subject to error from imprecision in estimation of crop mix.
3. METRIC estimates implicitly include adjustment for non-standard growing conditions, including both chronic and acute water-supply challenges.
4. There is no reliance on the ad-hoc adjustment for acute conditions, which were criticized in ESPAM1.1.
5. There is no need for reliance on the On-Farm algorithm. Note however that IDWR may wish to modify the On-Farm algorithm so that it does not change ET data, but still use it to partition percolation and runoff rather than directly use return-flow data.

The first two advantages are especially important for large counties where crop mix and water supply conditions may vary in space across the county, or where crop mix may vary by water source or irrigation provider.

However, METRIC images will never be available for all years in the calibration period. Some years do not have an adequate number of cloud-free days to allow calculation of METRIC estimates. Years in the early 1980s are hampered by lack of adequate ground weather data required for the internal calibration of the METRIC methodology, though ET_{Idaho}. contains reference ET (ETr) for all years of the 1980s.

For years with too many clouded images, an interpolation/extrapolation scheme may allow METRIC data from another year to be applied. For early years, either extrapolation may be applied or the SEBAL (Bastiaanssen et al, 1998) energy-balance algorithm may be used.[1] Data from satellites other than Landsat may also be considered. This report investigates the interpolation/extrapolation option, referred to simply as "interpolation" for brevity.

DATA

The following data were available:

1. METRIC evapotranspiration estimates for Landsat Path 39 and Path 40, for irrigation seasons 2000, 2002 and 2006.
2. METRIC-calculated ETrF (evapotranspiration fraction of reference evapotranspiration) for Path 39 and Path 40 for irrigation season 2002, and for Path 39 and the northern portion of Path 40 for irrigation season 2006.

[1] The SEBAL methodology was designed for use where ground-based weather observations are not available. Dr. Rick Allen of University of Idaho advises against this option.

3. Normalized Difference Vegetative Indices (NDVI) for the same time periods and locations as the METRIC-calculated ETrF data. NDVI is a satellite-derived indicator or measurement of the vigor and density of green vegetation.
4. Daily and monthly weather-station data for NOAA and Agrimet weather stations for both 2002 and 2006, for the entire Eastern Snake Plain.
5. Map of irrigated lands for 2006.

IDWR (2011(a)) provided the METRIC and NDVI data, while weather-station data were obtained from ET_{Idaho} (Allen and Robison 2006, 2009). The irrigated lands data were from ESPAM2.0 data sets (IDWR, 2011(a)).

METHODS

Overview

The basic method was to assume that the METRIC estimates for 2006 were the correct values, and to test the ability of various interpolation methods to reproduce 2006 values. In general, ET depth was calculated on a pixel-by-pixel basis using Equation (1):

$$ET = ETr * ETrF \qquad (1)$$

where:
- ET = evapotranspiration depth, mm
- ETr = reference evapotranspiration depth, mm
- ETrF = fraction of reference evaporation that becomes ET, dimensionless

The interpolation methods are alternate methods for calculating ETrF; hence, both interpolated and METRIC-derived ETrF values were multiplied by common ETr data to obtain comparable ET estimates for testing. Temporally, comparisons were made for the entire irrigation season and for each of the months April through October. Comparisons were made spatially on a pixel-by-pixel basis and on the basis of zones two miles by two miles in size, corresponding approximately to the smallest irrigation entities used in ESPAM1.1 and ESPAM2.0

Due to limitations in computer power, data and personnel time, the methods were modified from the original plan in the following ways:

1. Comparisons were only made for irrigated lands in Landsat path 39.

2. NDVI and ETrF data for the two years were consolidated to monthly values, and comparisons were made month by month rather than image date by image date.
3. Evaluations were confined to irrigated parcels and not extended to a surrounding buffer.
4. For each month, a single ETr (reference ET) value was used for the entire study area, rather than spatially interpolating ETr values from multiple weather stations.[2]
5. Rather than apply cloud masks, it was assumed that all data received from IDWR already included adjustment or interpolation for clouds. Hence, the tests will implicitly reflect the current methods for processing non-rejected cloudy images.

Interpolation Methods Considered

Naive Method. The first interpolation method was to simply apply the monthly ETrF values from the source year (2002) METRIC estimates to the ETr values used for the target year (2006). This was labeled the Naive method. Application of this method assumes the following:

1. While crops will change from year to year on any given parcel, within a reasonably small region the crop mix will be relatively stable from year to year.
2. General water supply conditions and non-standard growing conditions that would affect ET are similar in the source year and target year.

The Naive method would be distorted by acute water-supply conditions in either the source year or the target year; perhaps the source year has low supplies and the target year normal, or the source year has abundant supplies and the target low supplies. It also could be distorted by profound differences in crop mix, though such have not yet been observed in the county-wide NASS data relied upon in ESPAM1.1 and ESPAM2.0 (IDWR 2011(c); Contor, 2003). The Naive method has the advantages of providing an ETrF value for every month and of using the more sophisticated METRIC energy-balance algorithms for calculating ETrF.

NDVI Scaling Method. The Normalized Difference Vegetative Index derived from satellite data can also be used to calculated ETrF (Rafn et al, 2008). In this report the older term crop coefficient or Kc is used for NDVI-derived

[2] One implication of this is that the values reported here as "METRIC" for 2006 will differ from the actual METRIC values. This does not invalidate the comparison, because the comparison being made is between crop coefficients. The reference ET (ETr) only serves to weight summer months heavier than spring and fall months, and some spatial imprecision will not interfere with this function.

fractions, for distinction. While perhaps less precise than METRIC estimates, NDVI calculations have the advantage of requiring fewer data and significantly less personnel time that METRIC calculations. Eric Rafn (2011), formerly of IDWR, has developed a method to perform NDVI calculations using ESRI GIS products, which reduces the cost of required software. The NDVI scaling method tested here uses an equation from Dr. Richard Allen and others (Kramber, 2011):

$$Kc = 0.15 + 1.06 * NDVI \qquad (2)$$

Where: Kc = Crop coefficient, equivalent to ETrF
NDVI = Normalized Difference Vegetative Index

Rafn et al (2008) found that NDVI Kc equations appear to be robust over time and space; equations developed on corn in Colorado ten years earlier performed nearly as well as equations developed on all crops in an adjacent Landsat path in the year of the test. They also cited similar results from another researcher.

In applying the NDVI Kc fractions in the current test, it was assumed that there would be some missing dates in the target year; otherwise, METRIC estimates would be expected to be available and there would be no need for interpolation. Hence, random sampling was used to designate missing months within the target year, and Kc values were interpolated or extrapolated. For months assumed to have data, a ratio was calculated between the NDVI-derived Kc from Equation (2) using target-year data and the NDVI-derived Kc from the source year data. These ratios were used as multipliers to scale the naive estimates to the target year.

The idea is that the METRIC Kc from the source year implicitly reflects all the sophistication and advantages of the METRIC methodology, but it is missing information regarding acute crop type differences or acute stresses. Both crop mix changes and acute stresses should be highly correlated to vegetative index and hence detectable as a change in NDVI-derived Kc. In theory, then, the NDVI-scaled estimate should incorporate the long-term information available in the source-year METRIC ETrF, the target-year weather data contained in the target-year reference ET (ETr) and the acute crop type and stress information contained in the vegetative index.

The monthly approximation was calculated using Equation (3) if the unknown month was closer to one known month than any other, and using Equation (4) if the unknown month was equally distant in time from two known months.

$$Kc_m = ETrF_{m\ source\ year} * (Kc_{m'\ target\ year} / Kc_{m'\ source\ year}) \qquad (3)$$

$$Kc_m = ETrF_{m\ source\ year} * [(Kc_{m'\ target\ year} / Kc_{m'\ source\ year}) + (Kc_{m''\ target\ year} / Kc_{m''\ source\ year})] / 2 \qquad (4)$$

Where:
Kc_m = Interpolated Kc for month m in the target year
$ETrF_{m\ source\ year}$ = METRIC ETrF for month m in the source year
$Kc_{m'\ target\ year}$ = NDVI-derived KC for month m' in the target year
$ETrF_{m'\ source\ year}$ = METRIC ETrF for month m' in the source year
$Kc_{m''\ target\ year}$ = NDVI-derived KC for month m" in the target year
$ETrF_{m''\ source\ year}$ = METRIC ETrF for month m" in the source year

For example, suppose the NDVI Kc for June of the target year were 90% of the NDVI Kc for June of the source year, and July was to be represented using June's ratio. The Kc to be used for July in the target year would be 90% of the METRIC ETrF for July of the source year. If the June ratio were 90% and the August ratio 100%, July in the target year would be represented by a Kc of [(90% + 100%) / 2 = 95%] of the METRIC ETrF for July of the source year. In this report this concept is referenced using a notation of "Month from Month;" for instance, "July from May September" means that the July Kc is derived from the May and September ratios, applied to the July ETrF from the source year according to Equation (4).

Note that the definition of m' and m" depends on the data that are available. For example, if only May and September data were available, Equation (3) would be used for April and June, with May serving as m'. Equation (4) would be used for July, with May serving as m' and September as m". August and October would be calculated using Equation (3) with September serving as m'. If only one month of data were available, Equation (3) would always be used and the one month of available data would always be used as m'. Note also that calculations were performed pixel-by-pixel.

Interpolated Kc values were trimmed to a range of -0.05 to 1.5, to correspond approximately to expectations of agronomic and energy-balance limitations. Own-month NDVI-derived Kc values were not trimmed, nor were METRIC ETrF values used in the METRIC ET depth calculations.

Because both the Naive and NDVI scaling methods use target-year ETr (reference ET) data, they are equally responsive to weather-related differences in ET. In this test, the METRIC and both interpolation methods all used the same ETr data set, so that differences in ET are entirely a function of differences in ETrF or Kc.

Comparisons

For the test it was assumed that never would more than five months' data be available. Two random samples of five months were generated, two of three months, and four samples of one month. Table 1 lists the tests made, using the "Month from Month" notation. The colored italicized months are months where the random sample indicated data would hypothetically have been available. For instance, in Test 1-1 it was assumed that NDVI data were available for August of the target year. All other months in Test 1-1 used the METRIC Kc from the source year multiplied by the August fraction, per Equation (3).

Table 1
Interpolated Kc Values for NDVI Scaling Method Test

Month	**Test 5-1**	**Test 5-2**	**Test 3-1**	**Test 3-2**
Apr	*Apr_fr_Apr*	Apr_fr_May	*Apr_fr_Apr*	Apr_fr_May
May	*May_fr_May*	*May_fr_May*	May_fr_Apr	*May_fr_May*
Jun	*Jun_fr_Jun*	*Jun_fr_Jun*	Jun_fr_Jul	Jun_fr_May
Jul	Jul_fr_JunAug	*Jul_fr_Jul*	*Jul_fr_Jul*	Jul_fr_MaySep
Aug	*Aug_fr_Aug*	*Aug_fr_Aug*	*Aug_fr_Aug*	Aug_fr_Sep
Sep	*Sep_fr_Sep*	*Sep_Fr_Sep*	Sep_fr_Aug	*Sep_fr_Sep*
Oct	Oct_fr_Sep	Oct_fr_Sep	Oct_fr_Aug	*Oct_fr_Oct*
Month	**Test 1-1**	**Test 1-2**	**Test 1-3**	**Test 1-4**
Apr	Apr_fr_Aug	Apr_fr_May	Apr_fr_Jul	Apr_fr_Jun
May	May_fr_Aug	*May_fr_May*	May_fr_Jul	May_fr_Jun
Jun	Jun_fr_Aug	Jun_fr_May	Jun_fr_Jul	*Jun_fr_Jun*
Jul	Jul_fr_Aug	Jul_fr_May	*Jul_fr_Jul*	Jul_fr_Jun
Aug	*Aug_fr_Aug*	Aug_fr_May	Aug_fr_Jul	Aug_fr_Jun
Sep	Sep_fr_Aug	Sep_fr_May	Sep_fr_Jul	Sep_fr_Jun
Oct	Oct_fr_Aug	Oct_fr_May	Oct_fr_Jul	Oct_fr_Jun

(Note: Red indicates available data; black indicates interpolated estimates.)

For each of the tests, the full-season depth from the interpolation method was compared to the METRIC depth on a pixel-by-pixel basis and also on a zone-by-zone basis. Zones were comprised of four model cells and were intended to be a proxy for the smallest irrigation entities.

RESULTS

Full-Season ET Depths

The primary purpose of this investigation was to investigate the ability of interpolation to produce reasonable full-season spatially-averaged ET values. Figures 1 and 2 show that all but one of the methods produced ET depth estimates within 10% of the METRIC estimates, and almost half are within 5%. Table 1 explains the abbreviations used in the figures.

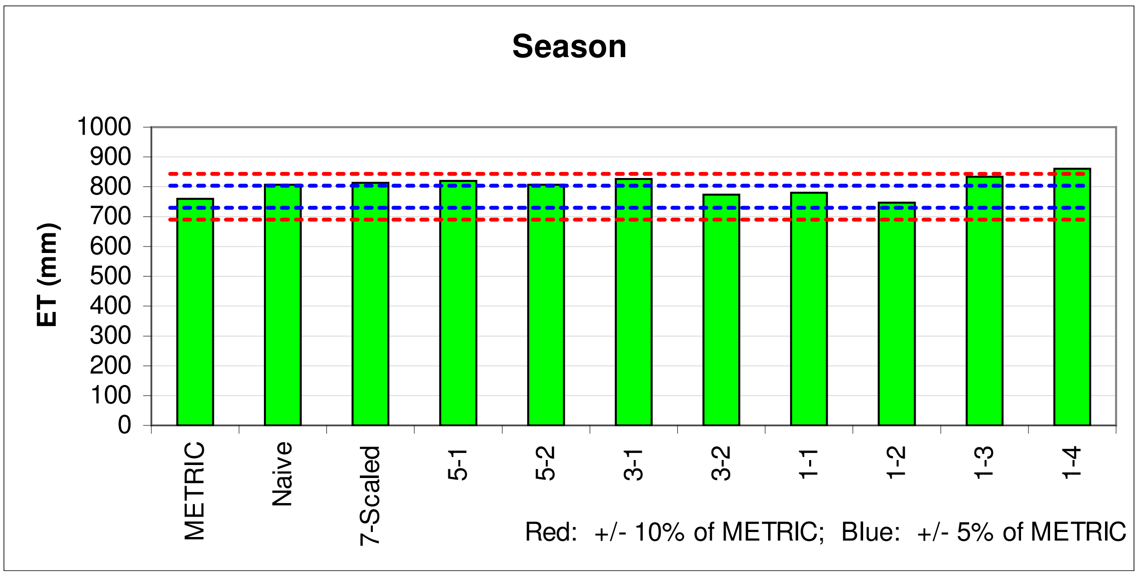

Figure 1. Seasonal ET depths from various methods.

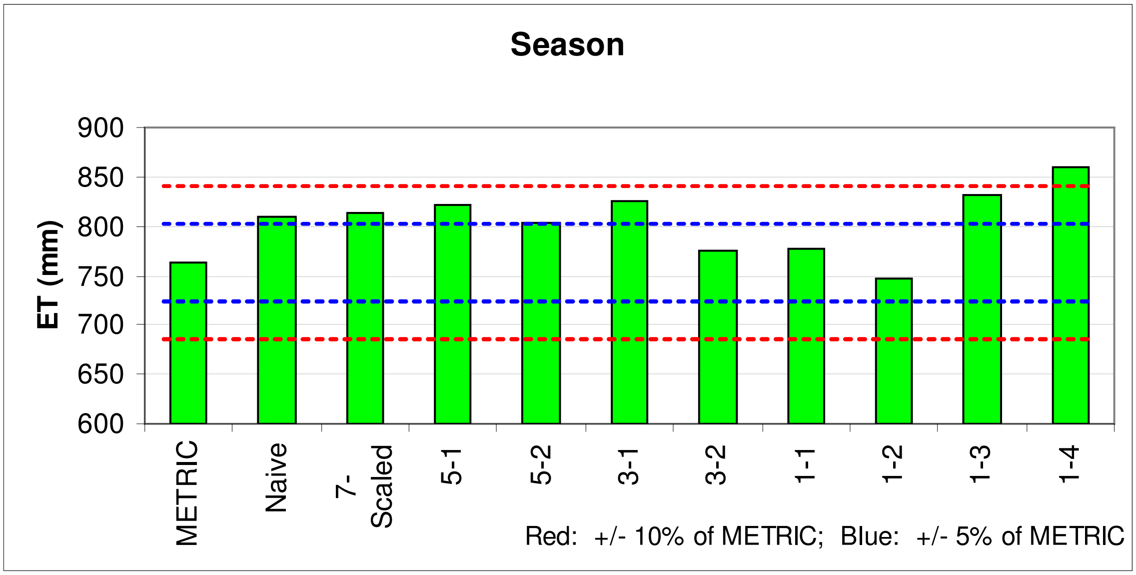

Figure 2. Seasonal ET depths from various methods, with vertical axis adjusted to emphasize differences.

Table 2
Explanation of Labels

Label	Description
METRIC	The METRIC ET estimated ETrF values for 2006 are applied to an estimate of year-2006 ETr, on a pixel-by-pixel basis. These data are used as the standard against which other estimates are compared.
Naive	This data set applies the METRIC ETrF from 2002 to the ETr from 2006, on a pixel-by-pixel basis.
Scaled data sets	The following data sets use various combinations of obtaining an estimated pixel-by-pixel Kc, using Equation (3) and Equation (4), and apply it to the ETr from 2006.
7-Scaled (or 7-Zone)	All seven months are represented using the own-month ratios of NDVI.
5-1	Five months are assumed to be known and two interpolated, per Table 1.
5-2	", second sample
3-1	Three months are assumed to be known and four interpolated, per Table 1.
3-2	", second sample
1-1	One month is assumed to be known
1-2	", second sample

Label	Description
1-3	", third sample
1-4	", fourth sample

Seasonal Differences Among Methods

The results also allow some consideration of seasonality. Figure 3 shows the 7-month seasonal pattern of three of the methods. Figures 4 through 10 compare the methods by month. In those figures, the "own month" scaled representation is colored yellow and the red dashed lines represent +/- 10% of the METRIC estimate.

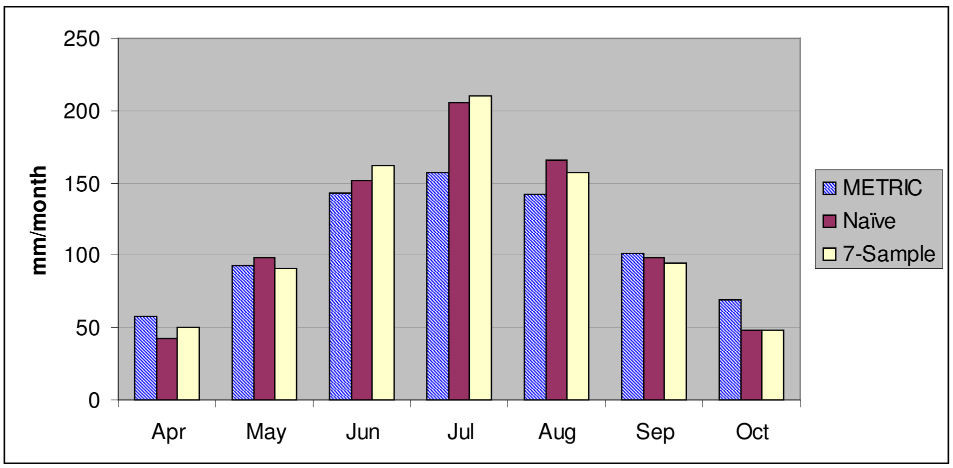

Figure 3. Seasonal pattern of METRIC, naive and 7-Sample scaled estimates.

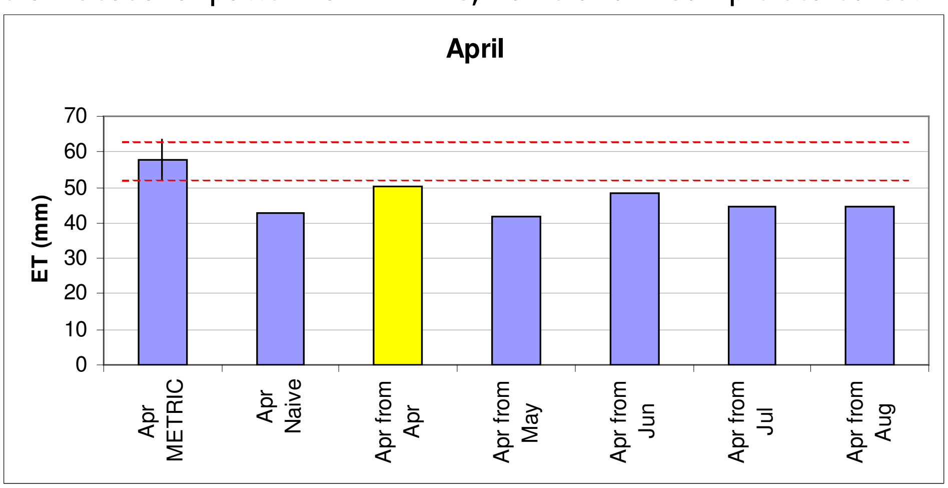

Figure 4. Estimates of April ET from various methods.

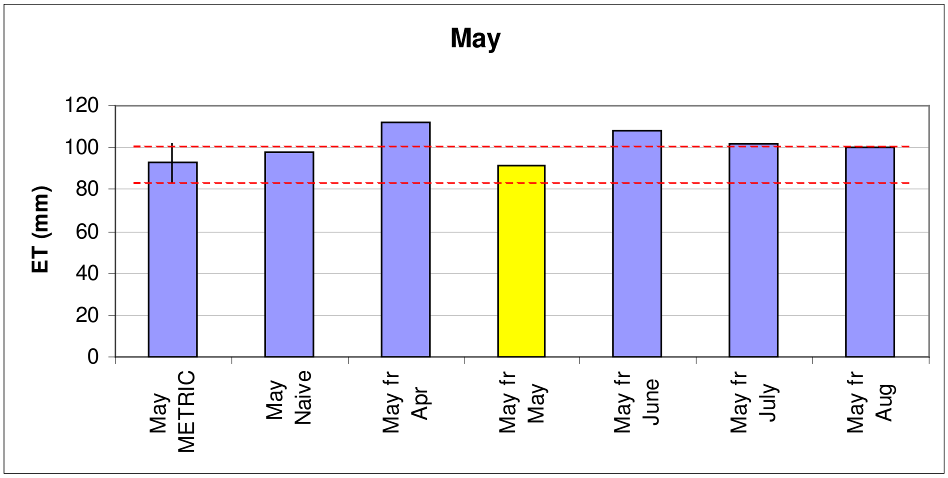

Figure 5. Estimates of May ET from various methods.

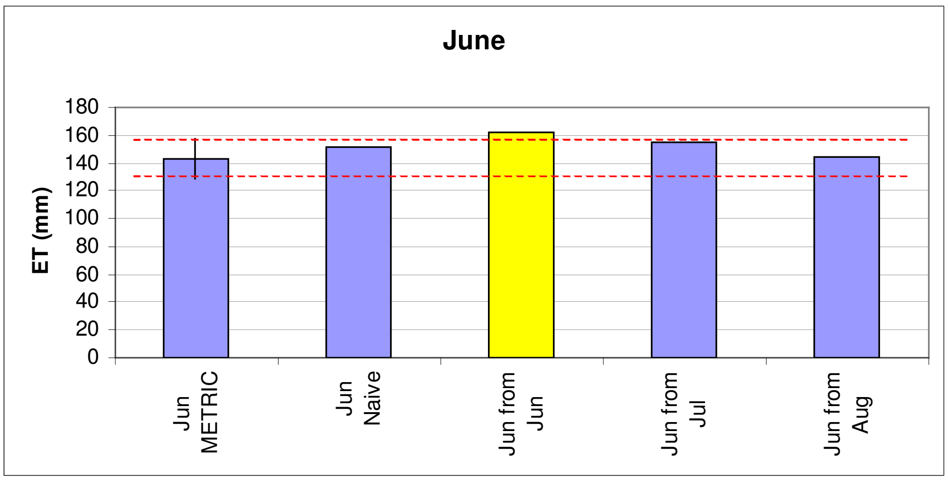

Figure 6. Estimates of June ET from various methods.

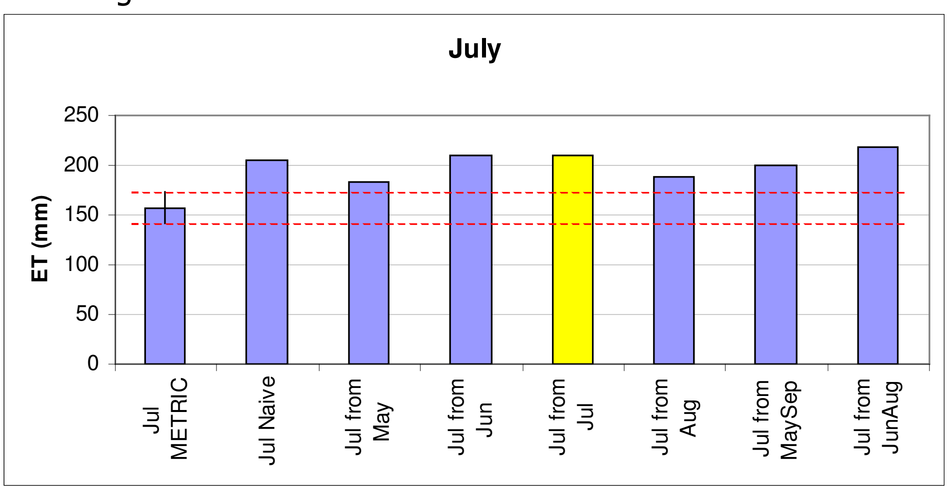

Figure 7. Estimates of July ET from various methods.

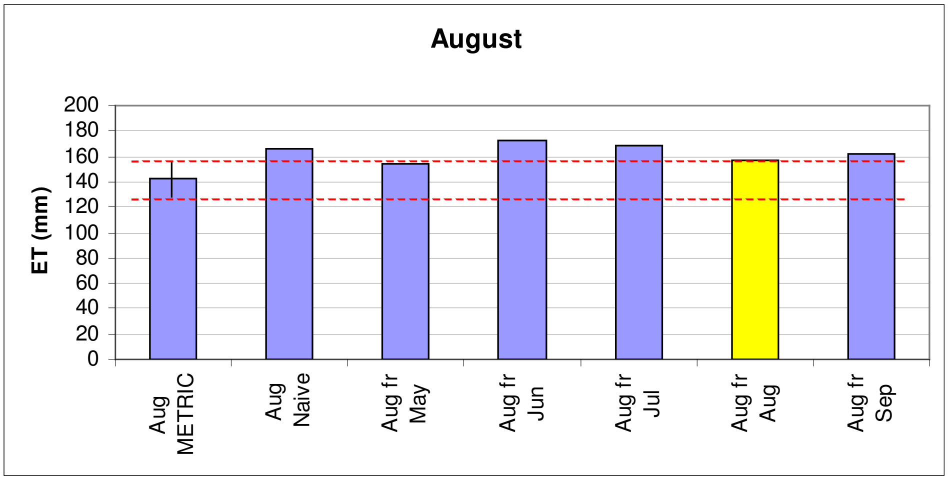

Figure 8. Estimates of August ET from various methods.

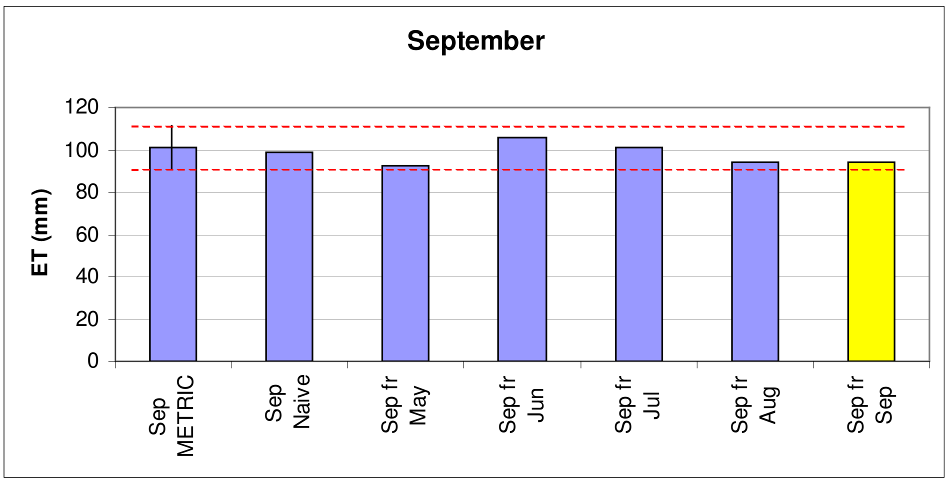

Figure 9. Estimates of September ET from various methods.

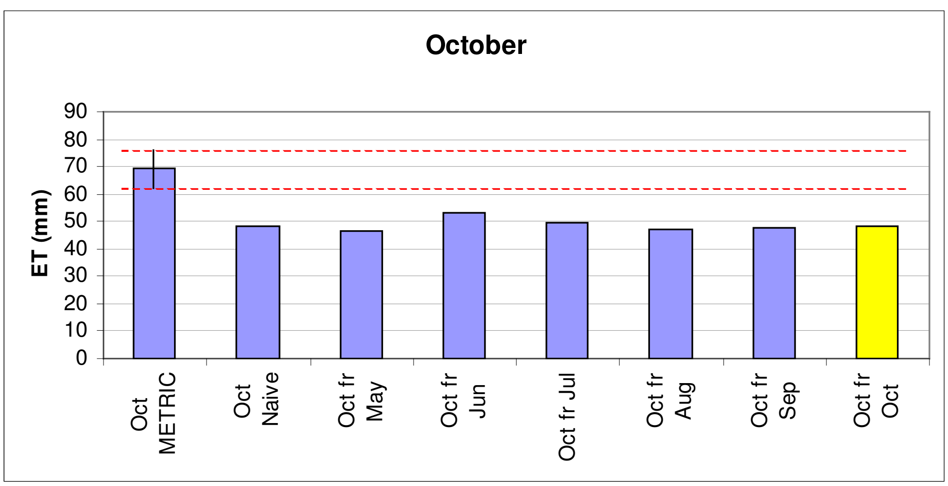

Figure 10. Estimates of October ET from various methods.

Appendix A shows the spatial distribution of monthly METRIC estimates for an arbitrary location, along with the full-season total METRIC ET depth estimate for the same location.

Spatial Distribution of Differences

The Naive method will be unable to detect parcel-by-parcel crop-rotation changes or crop mix changes. The NDVI scaling method should have some ability to detect these changes, based upon different seasonality of crops. Figures 11 and 12 compare the Naive method with the 7-sample method, which assumes NDVI data are available for all months. Of course the fewer sample dates available to the NDVI scaling method, the less able it should be to detect year-to-year crop differences. Figure 13 shows one of the NDVI interpolations using three dates, while Figure 14 shows an NDVI interpolation using only one date. Appendix B shows the spatial distribution of differences for all the interpolations tested.

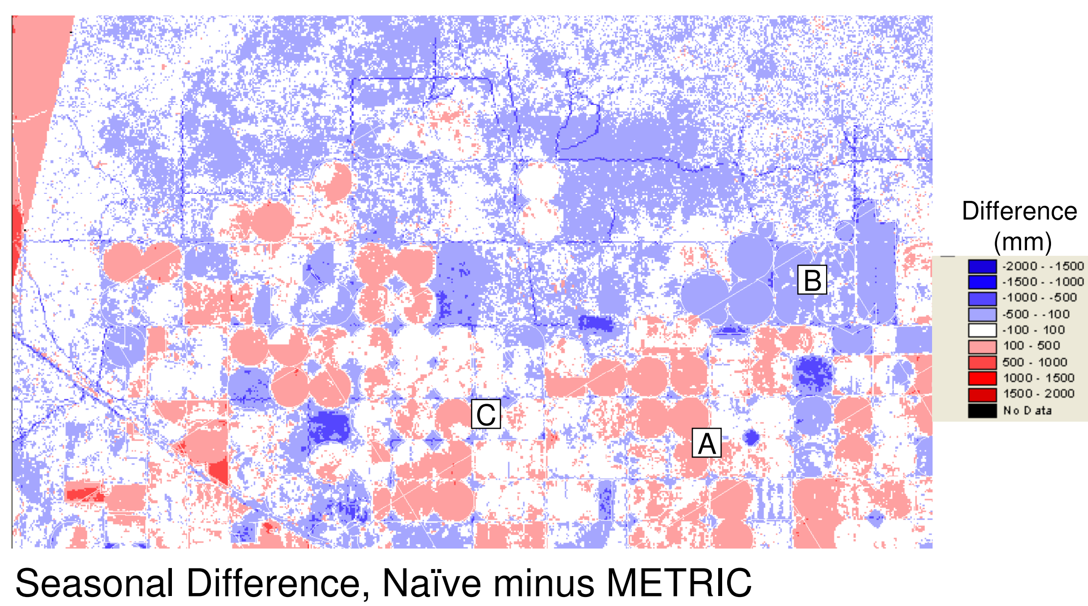

Figure 11. Spatial distribution of differences from Naive method. Lettered labels refer to discussion in the appendices.

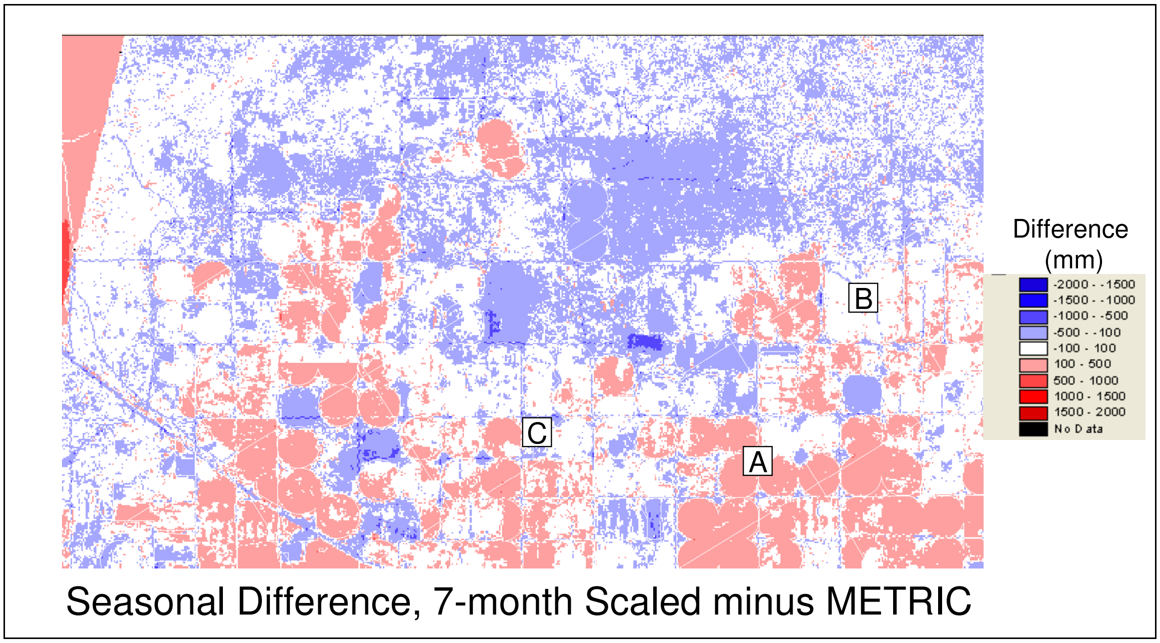

Figure 12. Spatial distribution of differences from NDVI scaling, assuming data are available for all seven months.

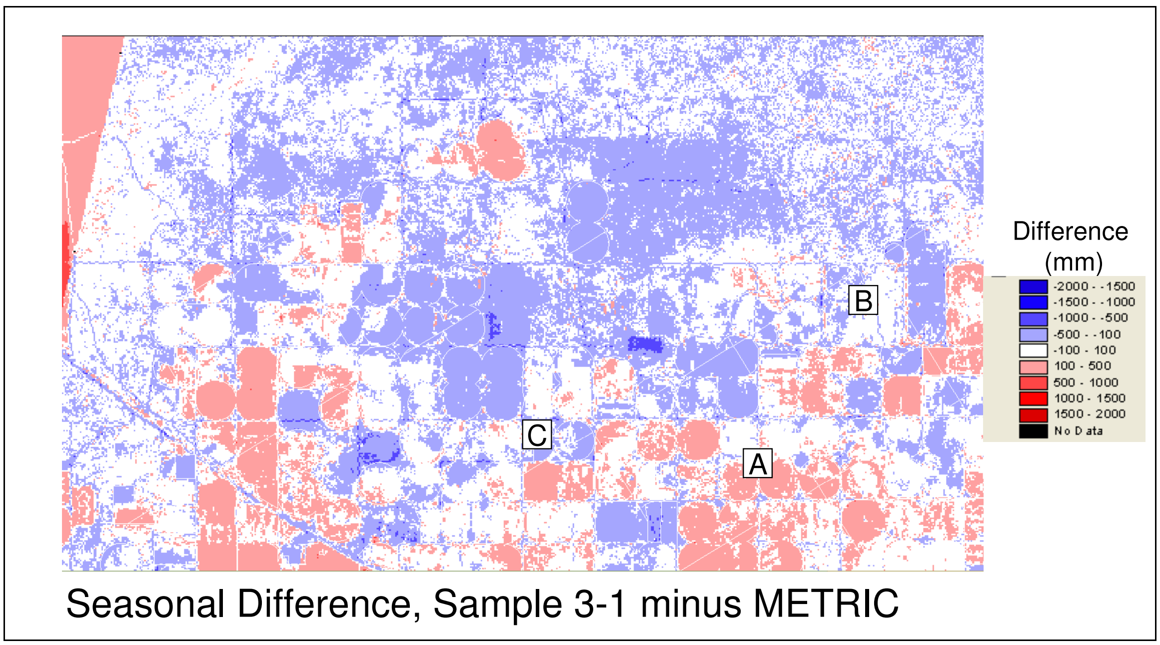

Figure 14. Spatial distribution of differences from NDVI scaling using three months of data.

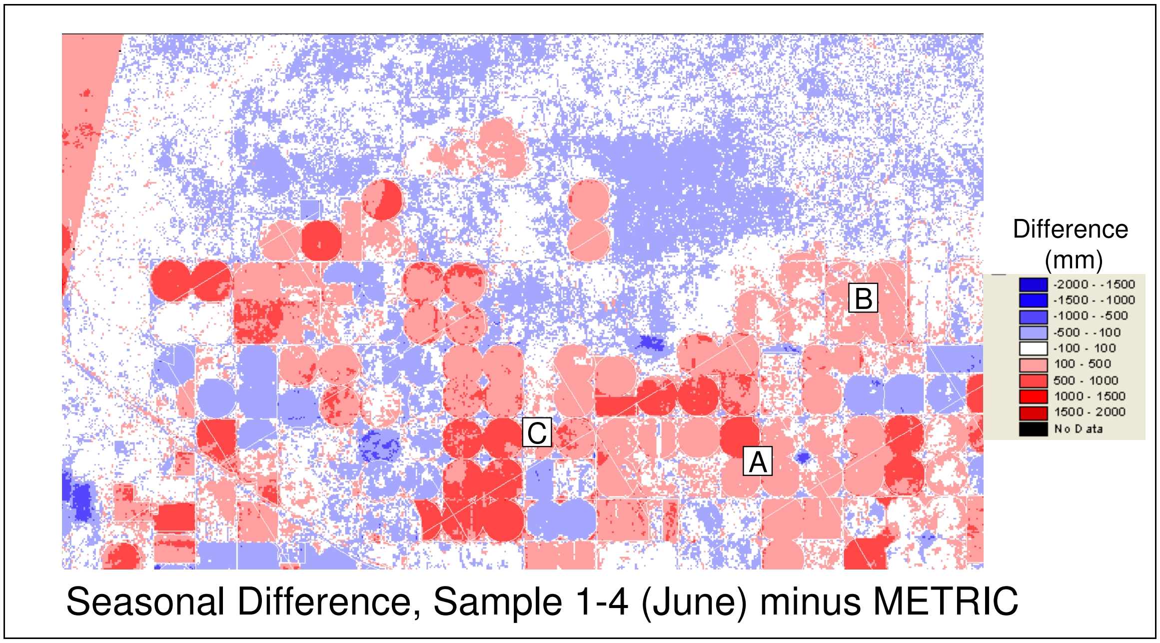

Figure 15. Spatial distribution of differences from NDVI scaling using only June data.

Insight into spatial imprecision can also be gained from the statistical distribution of differences, as shown in Figures 16 through 19. Figures 16 and 17 illustrate differences on a pixel basis. Since the total volume of ET is the desired end result, the pixel comparisons use mean and standard deviation. Figures 18 and 19 show zone-by-zone results. Since zones do not have equal irrigated acreage, median and quartiles were used to avoid distortion.

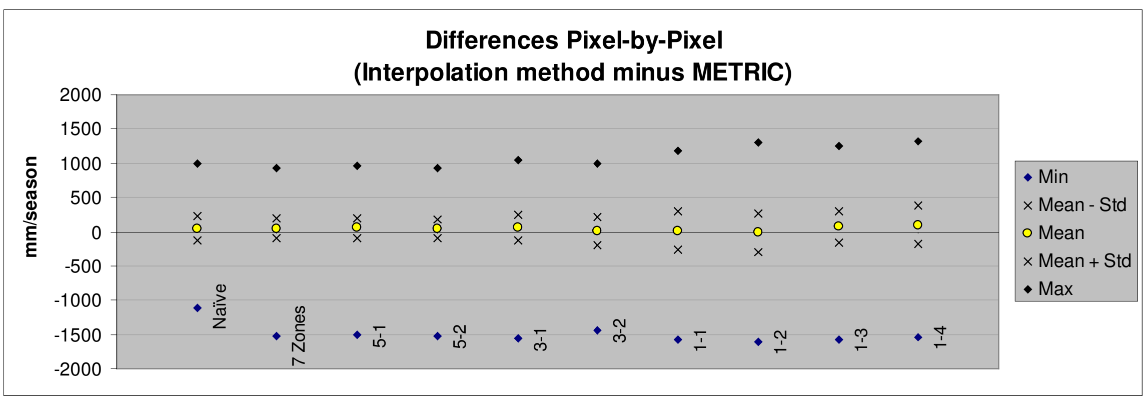

Figure 16. Statistical distribution of full-season differences on a pixel basis.

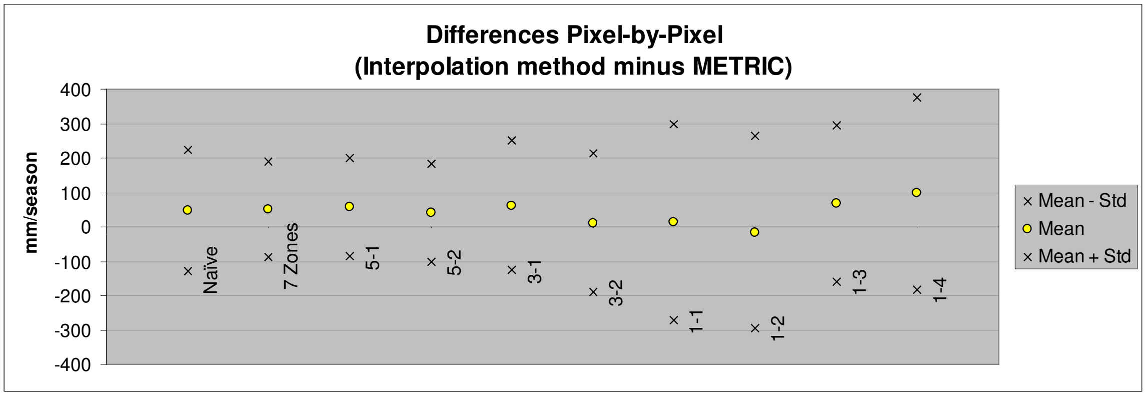

Figure 17. Figure 16 with the vertical axis expanded to exaggerate differences.

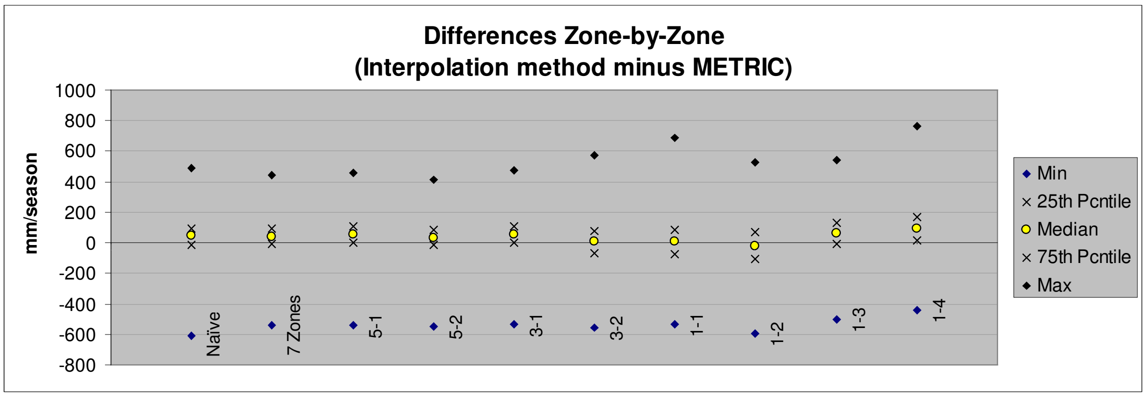

Figure 18. Statistical distribution of differences on a zone basis.

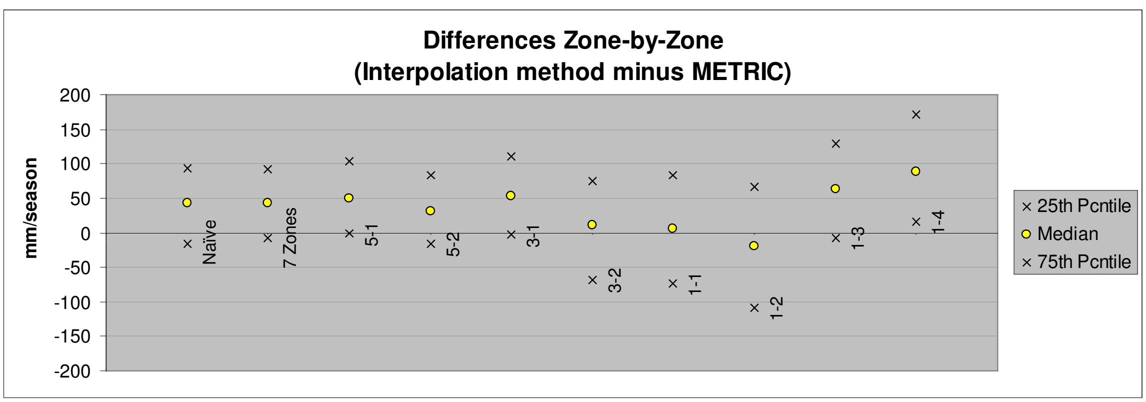

Figure 19. Figure 18 repeated with vertical axis expanded.

Summary of Results

All but one of the tests resulted in full-season average ET depths that were within 10% of the METRIC depth, and almost half were within 5%. Differences often exceed 10% on an individual month basis, but the general seasonal pattern represented by all the methods is reasonable.

Spatial distribution of imprecision (gauged by the appearance of pixels with more than 500 mm of absolute difference) seems to be lowest in the NDVI scaling samples using multiple months (Figures 12 through 14), slightly higher using the Naive method (Figure 11), and significantly higher when the NDVI scaling uses only a single month of data (Figure 15). By informal inspection, the by-pixel standard deviations weakly support this conclusion, while the by-zone quartiles do not.

DISCUSSION

The fact that an interpolation method is needed means that data are limited in the target year. This likely means that data will be limited for the NDVI scaling interpolation method, which may be a theoretical advantage for the Naive method. On the other hand, the NDVI scaling method can theoretically capture acute crop-mix or water-supply conditions in the target year, which the Naive method cannot.

The data do not strongly support either method, though no formal statistical analyses were performed. With the large number of pixels involved, even slight differences would likely be statistically significant, but of interest here are practical differences.

Average ET depths (Figure 1 and Figure 2) appear to support the Naive method, the individual-month data (Figures 3 through 10) do not appear to favor either method, and spatial distribution data (Figures 11 through19) may slightly favor the NDVI scaling method. However, year 2006 is not a year when either significant crop-mix changes or acute water-supply differences are known to have occurred. Hence, it can be argued that this test has not fully explored the theoretical advantage of the NDVI scaling method.

One option that has been discussed by reviewers is to use an NDVI-scaling method for months near in time to the month of available NDVI data, and the Naive method for other months. However, figures 4 through 10 do not particularly support this idea; without formal statistical testing, the own-month estimates appear as likely to be among the poorer estimates as among the better.

One theoretical advantage of METRIC over NDVI-based methods is that METRIC can capture evaporation that occurs from bare soil, while NDVI-based methods cannot. Figure 4 and Figure 10 could be construed as illustrations of this advantage, because in both cases it is likely that a significant portion of ET is evaporation from bare soil, since these represent April and October, respectively. However, in this case our expectation would be that the Naive method should be closer to the METRIC and different from the NDVI scaling method, since the Naive estimate incorporates all METRIC information, including bare-soil evaporation, from the source year.

This unsettling result is also apparent in the July results, and to a lesser extent in August. It shows markedly in Figure 3, and is also seen in Figures 7 and 8. In both these months, evaporation from bare soil should be at a minimum. Therefore differences in ET are expected to be functions of differences in crop mix, crop vigor and irrigation conditions, and the evaporative power of the atmosphere. Since the same ETr data were used for all three methods, only differences in crop mix and vigor (including effects of irrigation and water supply) remain to explain the differences between estimates. Both METRIC and NDVI scaling have access to information about changes in crop mix and vigor, but the Naive method does not. Hence, our expectation would be that METRIC and NDVI should tend to be more similar, and if there is a difference it should appear in the Naive method. It is not known why this expectation is not met.

RECOMMENDATION

Calculating ET for future version of ESPAM

It is strongly recommended that remotely-sensed ET estimates be used for future versions of ESPAM, and METRIC estimates in particular. Remote sensing offers the following advantages:

1. The spatial resolution is at a 30-meter or 60-meter scale instead of a county-wide scale. This is important where differences in crop mix, management practices, moisture stress or other departures from standard conditions might occur at a spatial scale smaller than a county or irrigation entity.
2. Remote sensing will implicitly account for differences between traditional calculations and in-field conditions. Actual ET could exceed traditional ET due to longer-season varieties, more intense management, increased use of other production inputs, and increased evaporation losses due to differences in frequency and method of irrigation. Actual ET could be less than traditional due to acute or chronic deficiencies in water supply, or any other acute or chronic stress except weed pressure.
3. Use of remote sensing will eliminate the need for both the ET Adjustment Factors and the portion of the On Farm Algorithm that reduces ET in instances of calculated deficit irrigation.[3] Both of these require significant effort and expose the water budget to additional

[3] The On Farm Algorithm can be entirely eliminated if return flow data are used directly, rather than having returns estimated by the algorithm.

assumptions and uncertainty. Both are specialized procedures developed within the ESPAM modeling effort and therefore may pose some defensibility challenges.

4. Use of remote sensing will greatly reduce the impact of imprecision in calculating the reductions for non-irrigated inclusions. These are applied to adjust for the lack of irrigation and ET on roads, haystack yards and other inclusions that may be represented as irrigated in various irrigated-lands data sets. The calculated reduction factors are hampered by two limitations: First, they rely on hand digitization from aerial imagery of varying sources and resolution; second, there is no mechanism to account for the increase in ET adjacent to these inclusions, due to advection of sensible heat. Remote sensing of ET will be robust to both these conditions.
5. With careful use of buffers, remote sensing might possibly be able to compensate for the effect of ET in adjacent non-irrigated parcels supported by sprinkler drift or runoff from irrigated lands.[4]

However, METRIC estimates will never be available for all stress periods of the calibration period. Hence, a temporal interpolation method is needed. For the two interpolation methods considered in this test, the agreement between the interpolated ET and target-year METRIC ET is generally within 10% and often within 5%, even when few target-year data were used to constrain the interpolation. ESPAM1.1 and ESPAM2.0 methods offer both data-gathering challenges and significant shortcomings in spatial and temporal resolution of crop ET data. Neither has a satisfying response to potential acute differences in crop distribution or water supply. For these reasons it is recommended that future ESPAM versions use METRIC ET data for all available years, and interpolated or extrapolated Kc or ETrF (crop coefficient) values applied to target-year ETr (reference ET) for all other years.

The NDVI scaling method performed well in this test and offers the important advantage of theoretically being responsive to acute crop-mix and water-supply conditions. Except when only one month of data was available, it generally did as well as the Naive method in estimating total ET depth, and may have been slightly superior in spatial distribution. Therefore, it is recommended that the NDVI scaling method be used whenever at least two NDVI-based Kc data sets can be calculated, and the Naive method be used otherwise.

Further Work

Two important tasks need to be addressed prior to implementation in ESPAM. The first is to address the spatial distribution of surface water across

[4] In ESPAM2.0 there has been an effort to include these effects in the calculation of ET Adjustment Factors.

irrigated lands. In ESPAM1.1 and ESPAM2.0, surface water was uniformly distributed, as was ET. However with the use of METRIC, ET will not be uniformly distributed, and it may appropriate to also modify distribution of applied irrigation water. This concern is especially important on a month-to-month basis.

The second needed task is to consider the implications of applying METRIC ET to a buffer around irrigated lands, to potentially capture the effects of local wind drift or runoff that supports ET in non-crop areas. This evaluation could also consider the advisability of expanding the buffer to include wetlands and/or residential and urban areas.

Additional tasks may also be considered. RAFN et al (2008) found that NDVI Kc relationships developed in Colorado many years previously were useful in Idaho in the 2000s, and reported similar results from another researcher. This suggests that NDVI algorithms are robust to time and location. Nevertheless, when the 1986 METRIC data for the Eastern Snake Plain become available it may be useful to compare NDVI scaling results for those estimates as well.

Finally, IDWR and the ESHMC may wish to test other combinations, such as applying NDVI scaling to some months and the Naive method to others, or using a Naive method that averages ETrF values from multiple source years. They also may wish to consider using METRIC estimates from other satellites for time periods when LANDSAT data are insufficient for METRIC calculations.

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APPENDIX A

Spatial distribution of METRIC ET estimates for an arbitrary sample location

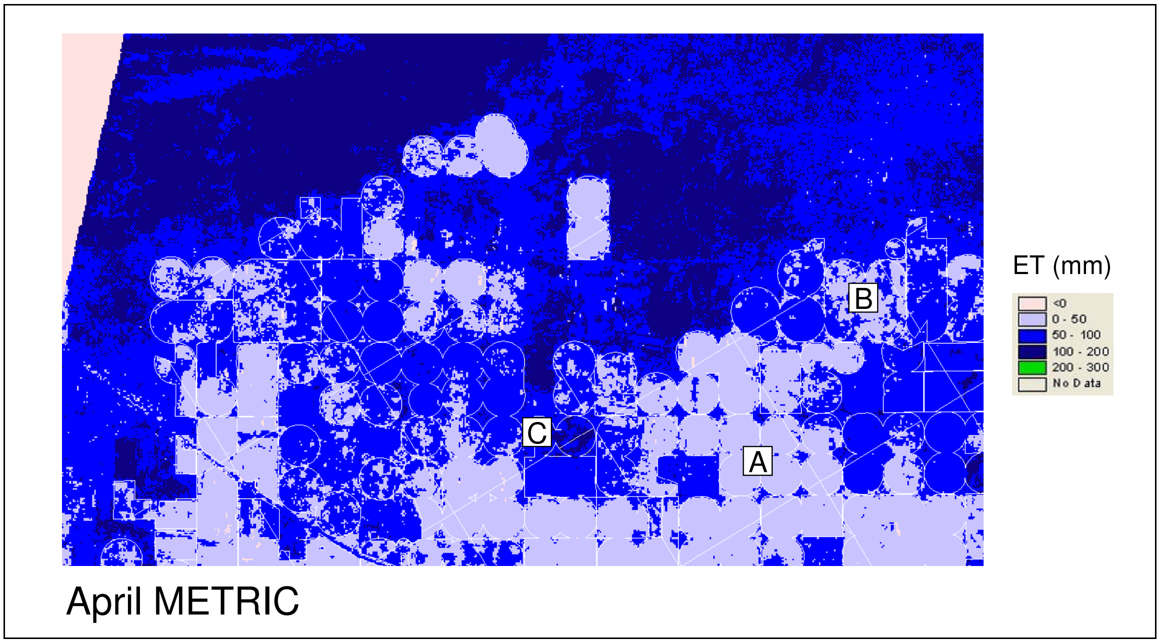

Figure A1. April METRIC ET estimates.

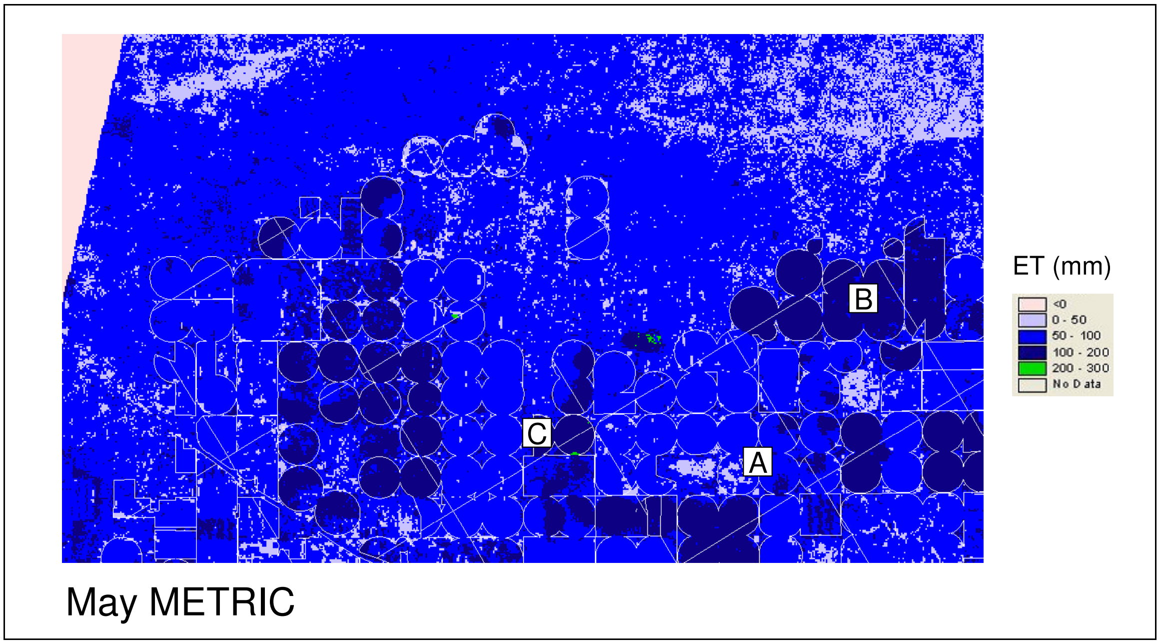

Figure A2. May METRIC ET estimates.

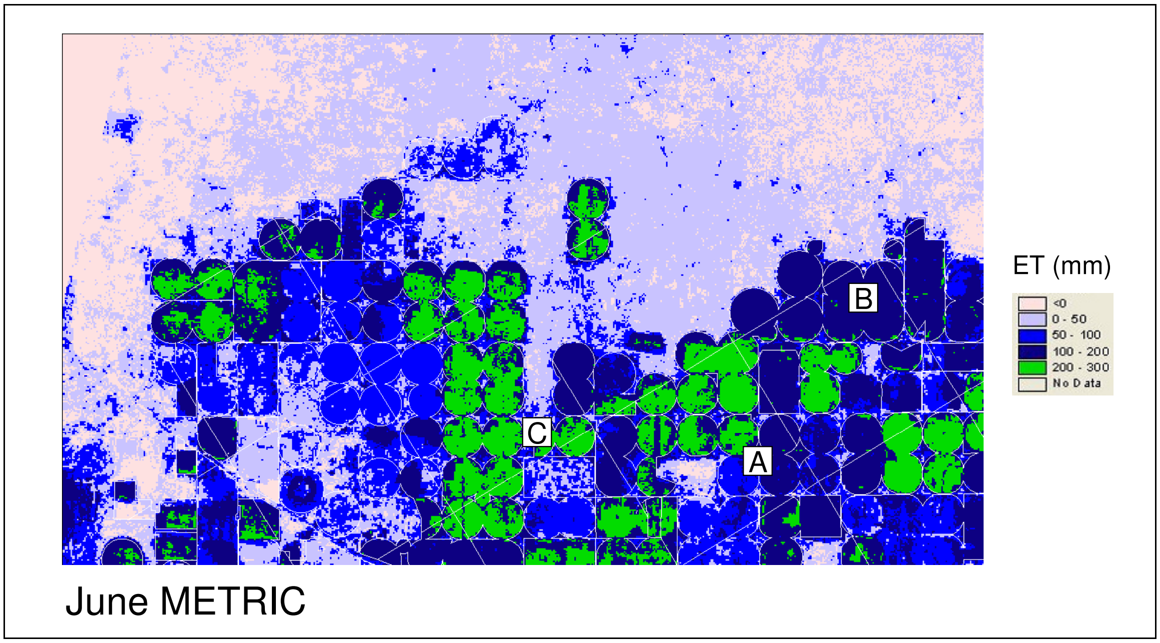

Figure A3. June METRIC ET estimates.

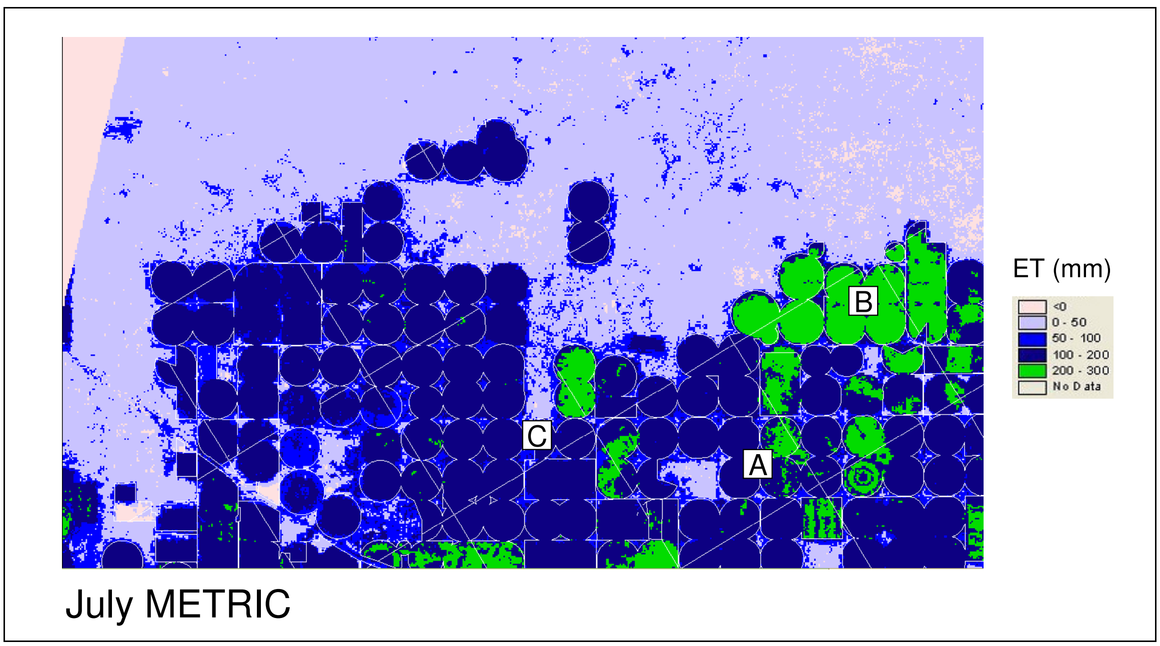

Figure A4. July METRIC ET estimates.

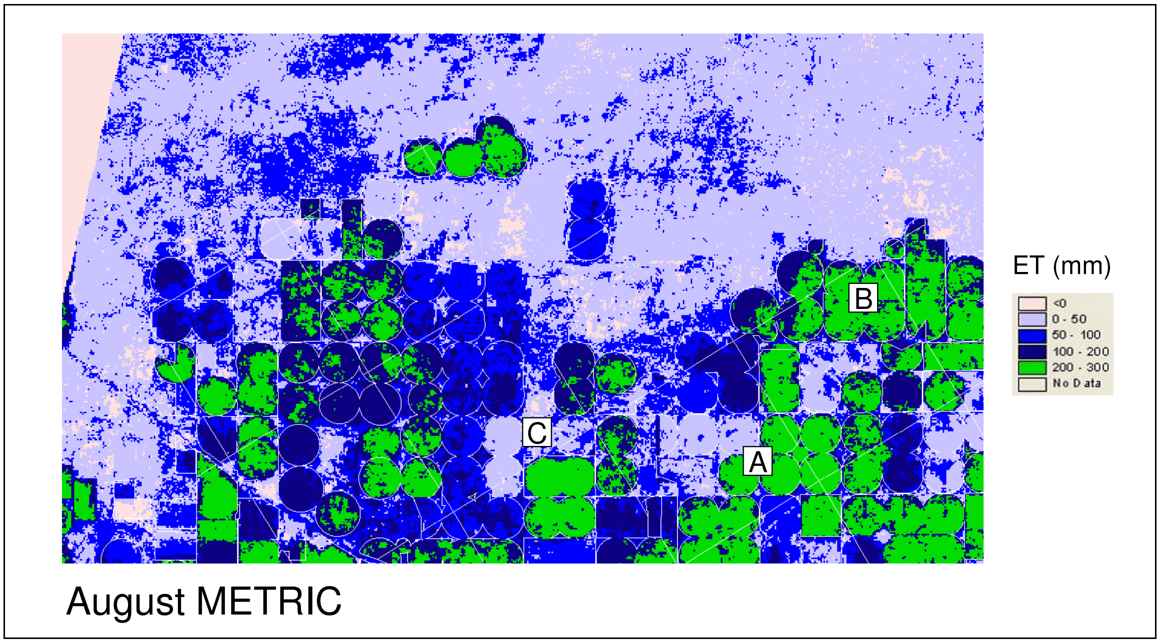

Figure A5. August METRIC ET estimates.

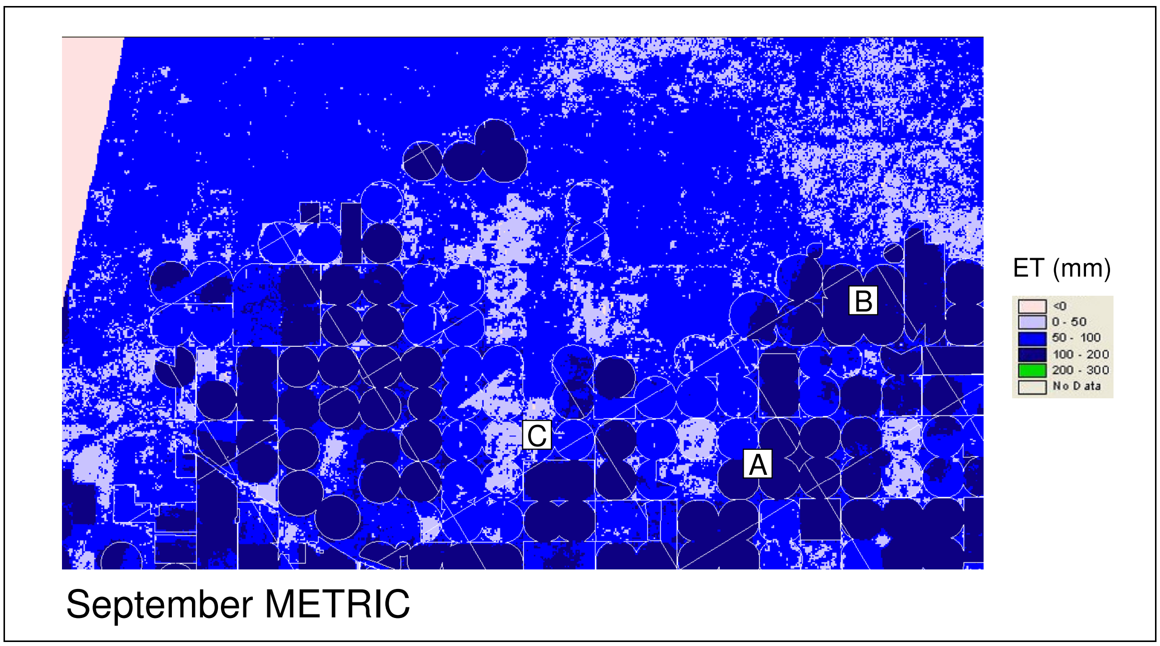

Figure A6. September METRIC ET estimates.

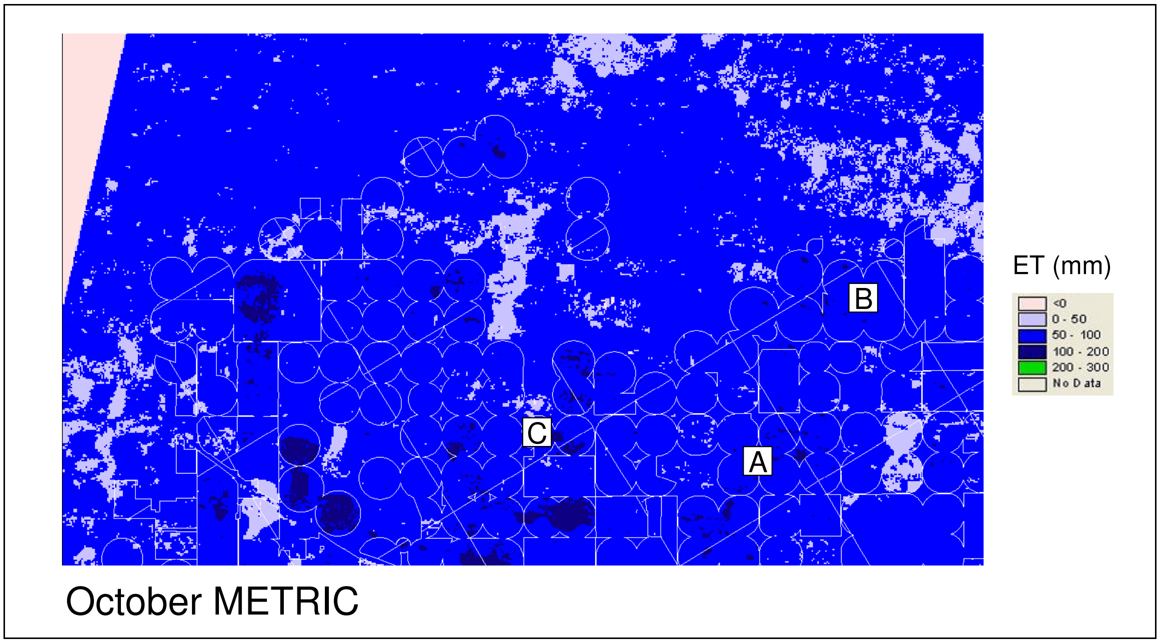

Figure A7. October METRIC ET estimates.

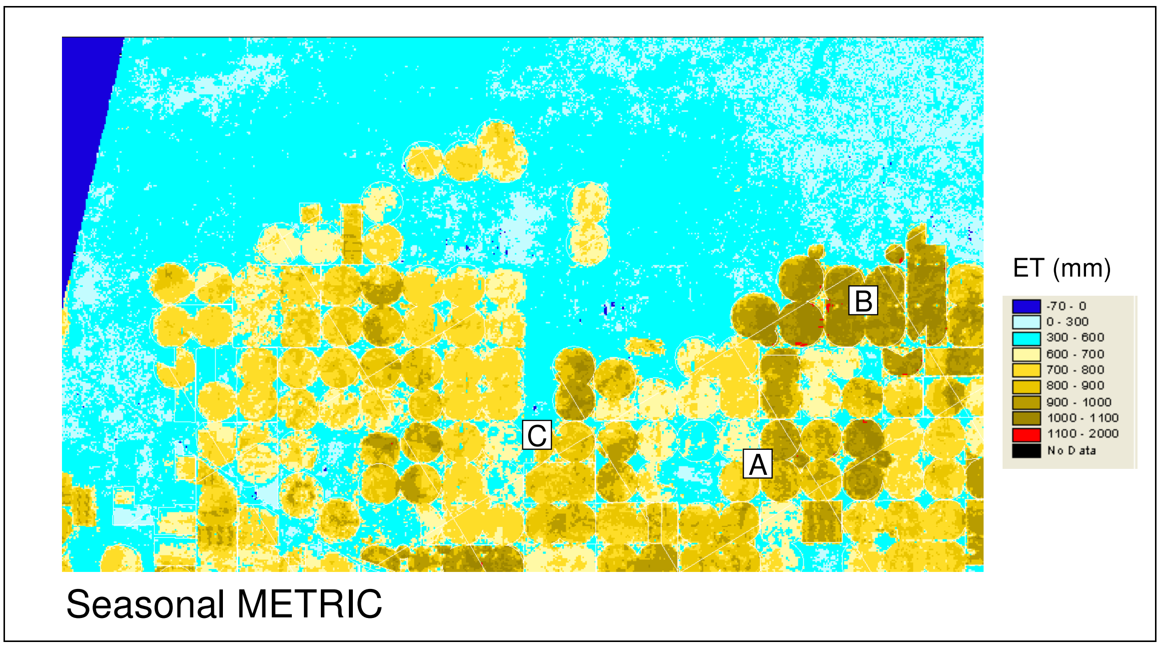

Figure A8. Seasonal METRIC ET estimates.

Discussion

The two pivots east of letter A have lower ET in early months and higher ET in later months. Full-season ET is moderately high. This is consistent with sugar beets or to a lesser extent, potatoes. The four pivots at letter B are generally high in ET in all months, and have high ET for the season. This is consistent with alfalfa. The pivot east of letter C starts with high ET early on, but drops quickly. Full-season ET is moderately low. This is consistent with winter grain.

Appendix B shows the full-season differences for the same sample area.

APPENDIX B

Spatial distribution of differences between METRIC and tested interpolation methods for an arbitrary sample area.

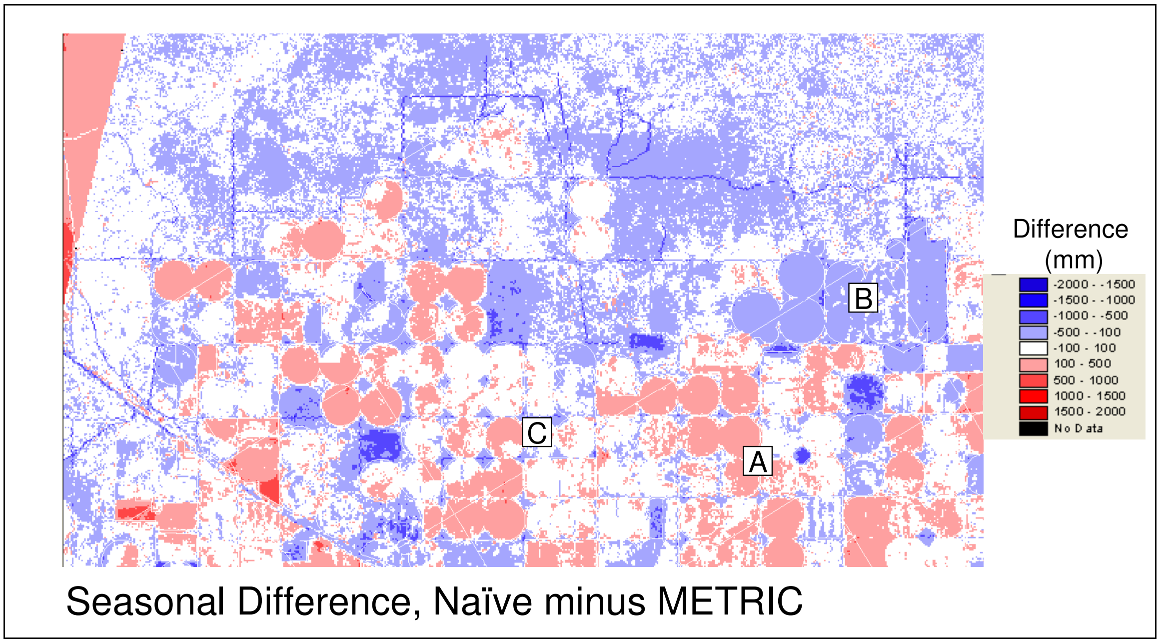

Figure B1. Seasonal differences between METRIC and the Naive method.

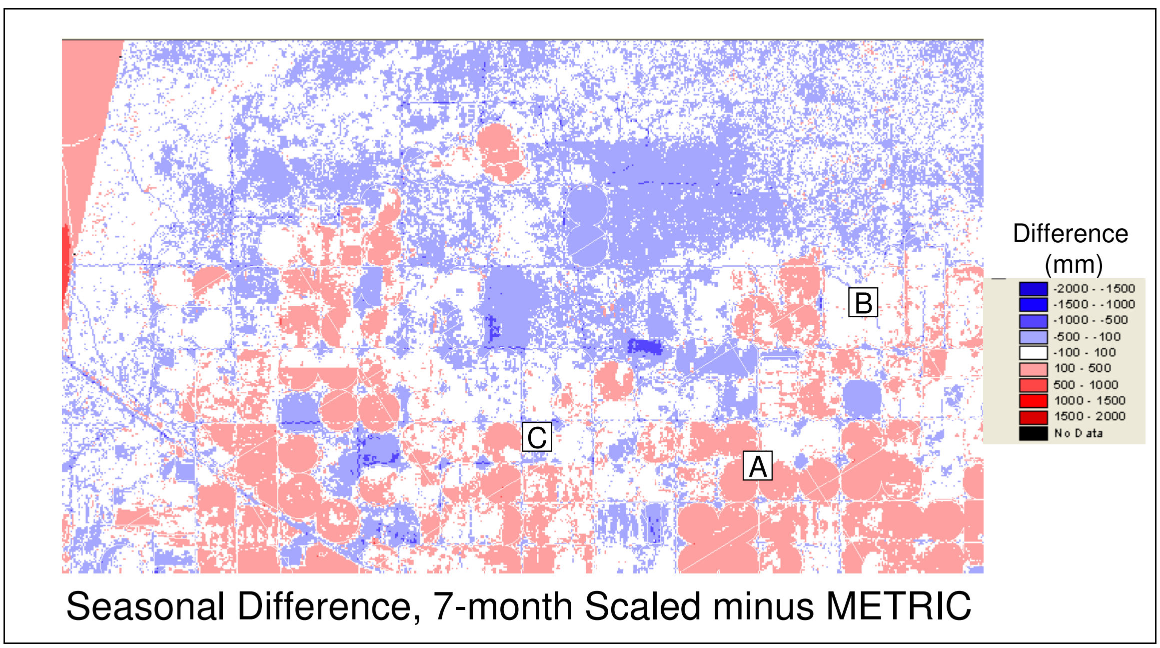

Figure B2. Seasonal differences between METRIC and the 7-month (7-scaled or 7-zone) NDVI-scaled method.

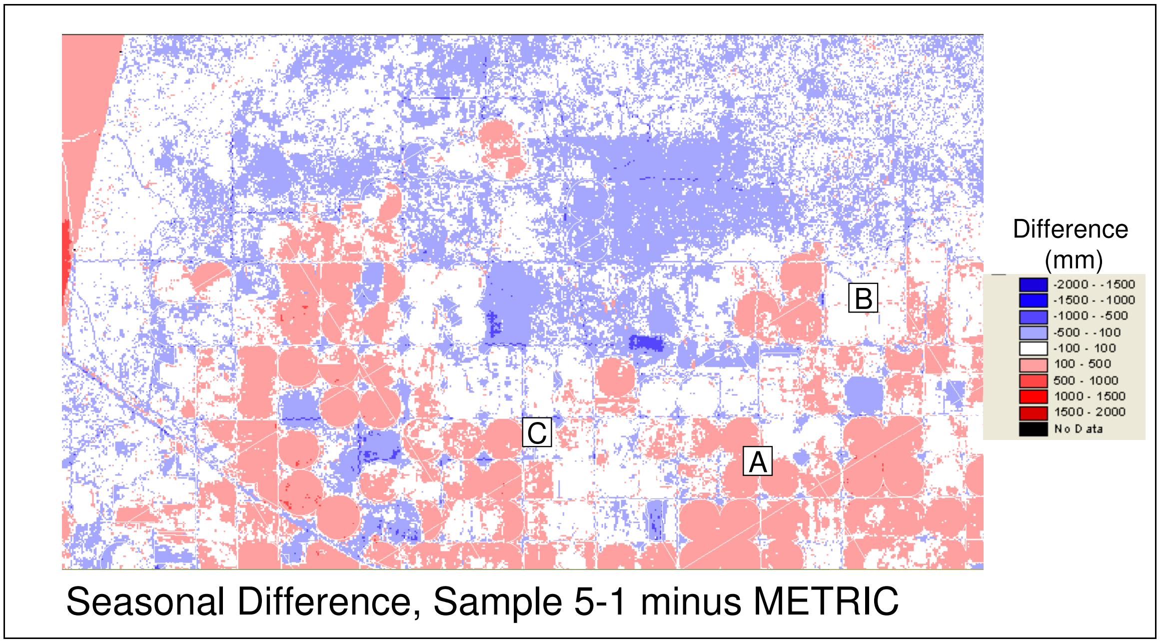

Figure B3. Seasonal differences between METRIC and the 5-1 sample of the NDVI-scaled method.

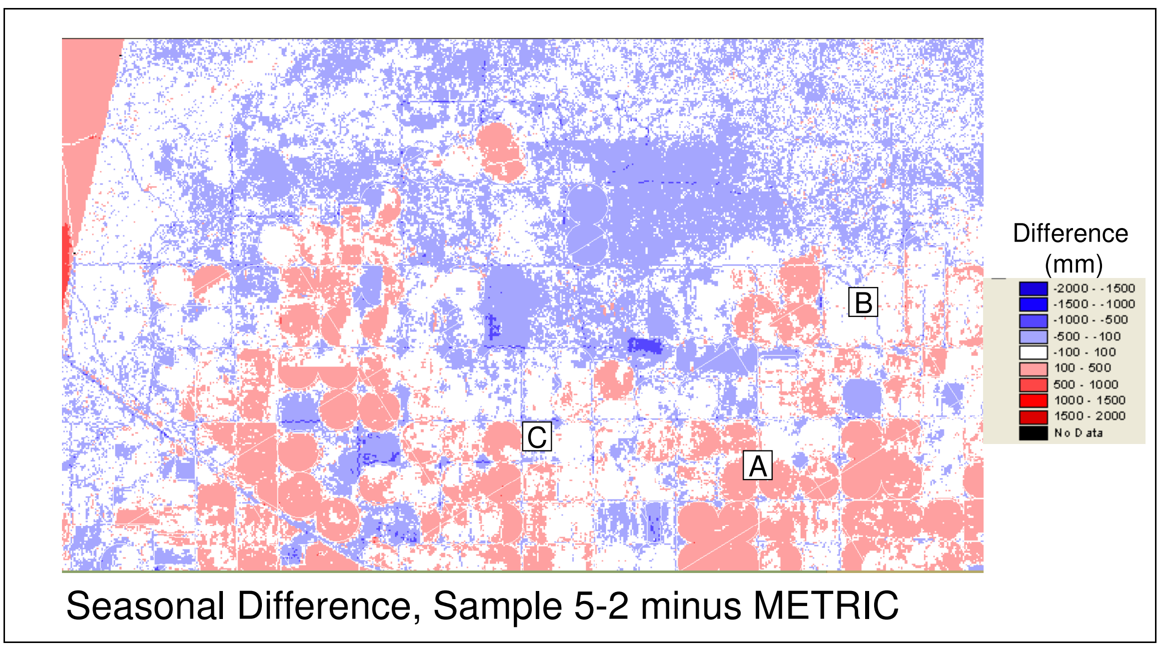

Figure B4. Seasonal differences between METRIC and the 5-2 sample of the NDVI-scaled method.

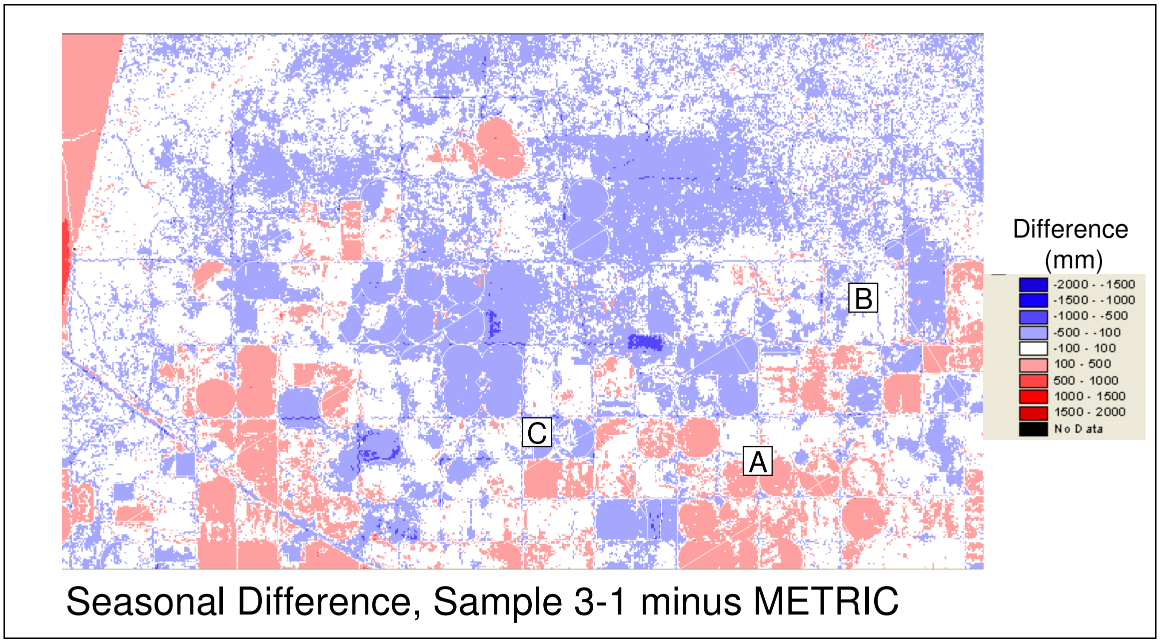

Figure B5. Seasonal differences between METRIC and the 3-1 sample of the NDVI-scaled method.

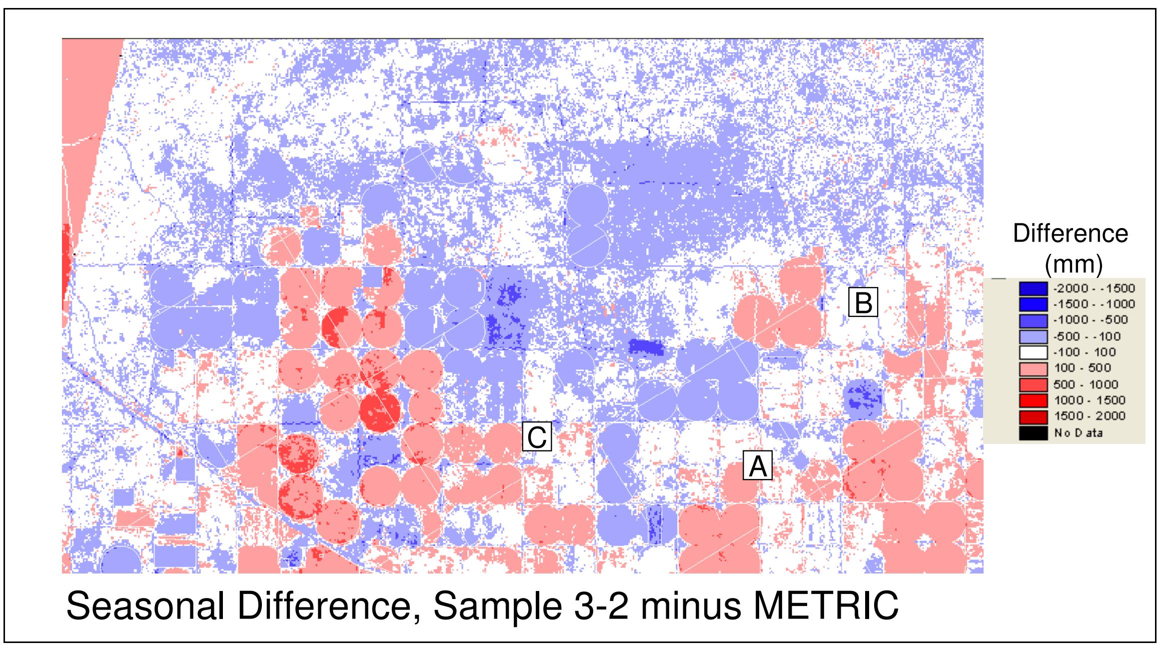

Figure B6. Seasonal differences between METRIC and the 3-2 sample of the NDVI-scaled method.

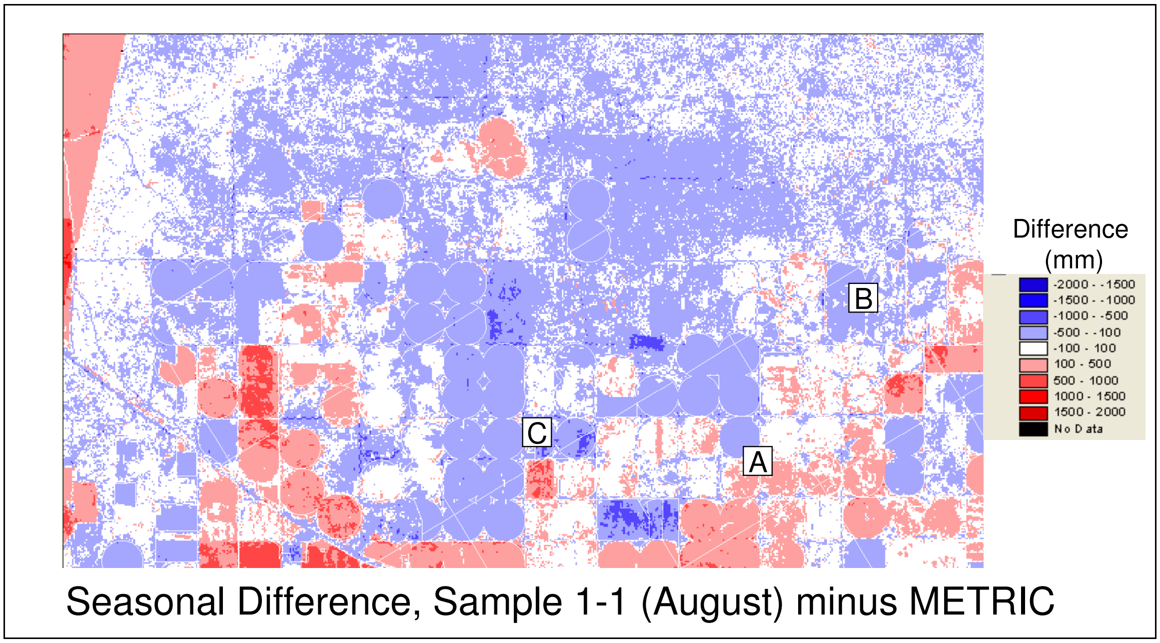

Figure B7. Seasonal differences between METRIC and the 1-1 sample of the NDVI-scaled method.

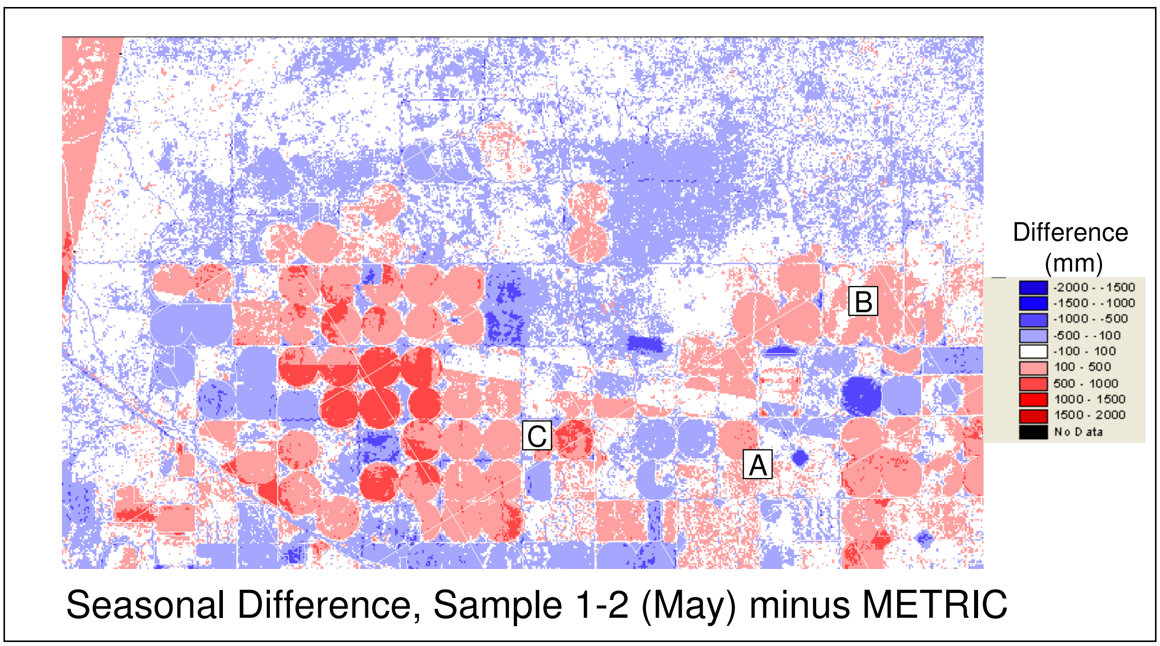

Figure B8. Seasonal differences between METRIC and the 1-2 sample of the NDVI-scaled method.

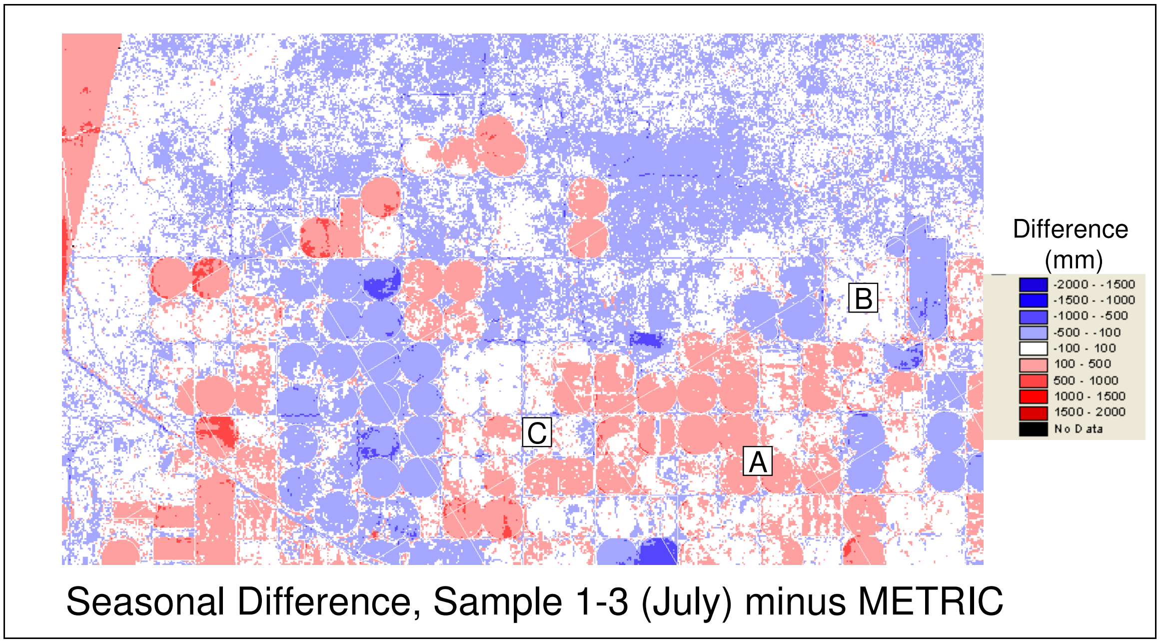

Figure B9. Seasonal differences between METRIC and the 1-3 sample of the NDVI-scaled method.

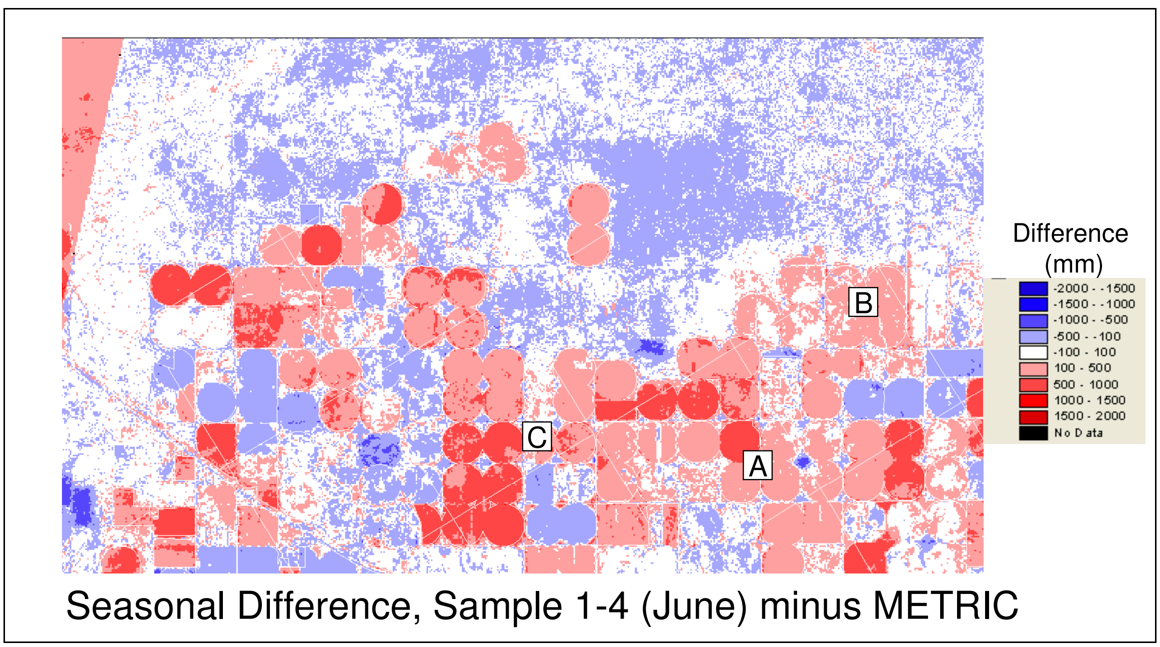

Figure B10. Seasonal differences between METRIC and the 1-4 sample of the NDVI-scaled method.

Discussion

Appendix A identified the field east of letter A as possibly sugar beets or potatoes. These are short-rotation crops and therefore it might be expected that

Naive-method differences would be large, as would single-month NDVI-scaled estimates. However, all differences are remarkably low.

Parcel B was identified as possibly alfalfa. Differences are generally low. The low Naive difference could be consistent with the longer rotation period of alfalfa; the parcels may have had the same crop in the source year as in the target year. The low differences for the various NDVI-scaling samples are consistent with an expectation that because alfalfa is green all season long, any of the samples would produce similar results.

Parcel C was indicated as possible winter grain. The Naive difference is low, consistent with a fairly long rotation period for some grain parcels. The single-month NDVI-scaled results correspond to this expectation; May (Figure B8) and June (Figure B10) results show that the NDVI-scaled method over-estimates full-season ET, consistent with an observation of green lush growth in those months. Similarly, July (Figure B9) and August (Figure B7) estimates tend to under-predict, consistent with an observation of mature or harvested vegetation in those months.

Figure B8 shows an odd diagonal anomaly across the middle of the image. This is likely related to underlying satellite data in either the NDVI or METRIC calculations, or perhaps to a cloud mask.